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Physiological Factors Affecting Quality And Safety In Production Environments

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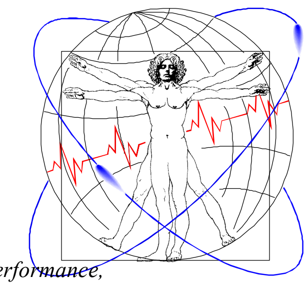

ABSTRACT

Physiological and psychological influences affect the reliability of human performance, particularly in shift work production environments. These influences affect all personnel and include in part the quality and quantity of sleep achieved, the effects of sleep loss, circadian influence and phase, time on task, consumption of caffeine and alcohol, the side effects of many over-the-counter and prescription medications, and other factors that are known to have an effect on performance, response time, cognition, memory, and mood state. These factors affect the quality and safety of the product, process and personnel, and should be considered throughout all phases of design, management and production.

NOMENCLATURE:

FIM, Fabrication, Installation and Modification
HOF, Human and Organizational Factors
OSHA, Occupational Safety and Health Administration
CFR, Code of Federal Regulations
REM, Rapid Eye Movement
NREM, Non-Rapid Eye Movement
CHD, Chronic Heart Disease
OTC, Over-the-Counter medications
process, quality, sleep, fatigue, circadian influence

INTRODUCTION

The purpose of this paper is to present an overview of the physiological and psychological influences that are known to affect the quality and safety of human performance in the Fabrication, Installation and Modification (FIM), environment. The term FIM and "production environment" may be used interchangeably herein.

These influences are considered germane to all functions, including management and administration, design, production, subcontract and inspection personnel alike. In so much as similar vigilance, performance, quality and safety are required of either in cooperation with or the absence of each other.

This review does not intend to be comprehensive. Other social and behavioral influences exist that should be considered when evaluating the safety and quality of work environments in general, and whenever changes are planned or implemented. Nevertheless, this review will highlight a selected nucleus of factors that have been determined to negatively affect human performance in the FIM and other production environments. Each of these factors have been validated to some degree through numerous research projects that have served to establish general parameters regarding the capabilities of humans as participants in, or monitors of, a wide range of tasks.

These research initiatives have spanned many operational environments and have reached sufficiently similar conclusions regarding human ability and performance for these factors to be considered an inescapable reality of normal human physiology and psychology.

Further are these influences believed to be indifferent to corporate status, wage, earning potential, experience, subjective estimates of personal professionalism, and to some degree social, motivational, and personality factors, as well.

For example, even highly motivated, strong willed, intelligent and responsible personnel, such as commercial flight crews [1], are poor monitors of mundane, slow to change, or infrequent events [2]. This is true despite that they are well educated, trained, and highly compensated, and, generally work in a less severe physical environment than the average FIM worker.

Additionally when humans become tired and or are not feeling well, tasks that require maintaining vigilance in a poor contrast environment, an environment with little or no activity, or in an environments that is very busy [3, 8], are less likely to be performed at the level that the designer of the task or system might have modeled or envisioned. Humans are also likely to adopt complacent attitudes or behaviors when required to monitor events that they have become habituated to [4], and/or systems that are normally reliable.

When considering the FIM environment, many examples of tasks and work stations that possess one or more of these undesirable qualities, exist. Examples of these include yard crane cabs, security posts, operating control stations, and others. Tasks and environments also vacillate between periods of minimal activity or involvement of the operator and periods of high demand. Frequently these fluctuations are controlled by or are expected to be reflexive to another person, cue, or effort - often in cooperation with human and computer controlled equipment. It is therefore essential that environments, tasks and those controlling them, consider the effect that the design and nature of the work environment or task will have on the human working therein.

Typical FIM environments by their nature and geographic location often present less-than-optimal working conditions. Many of these conditions are largely beyond the control of those working in or responsible for managing them and the processes that occur within them. Nevertheless, the effects of the daily and seasonal ranges of extreme heat, cold, humidity, and vibration that are common to these environments, cannot be divorced from the quality and safety of the production process or outcome.

This is true whether the environment be ambient [5], or a confined space (such as a yard crane cab) [6], process control room, or administrative area [7]; whether they are artificially or naturally lit [8].

Given so many independent variables to manage, the essential element responsible for achieving, maintaining, or improving quality and safety remains invariably human. For this reason it is imperative that owners, insurers, designers, managers, and operators of production environments, focus on the humans operating in the FIM system as systems in and of themselves.

Further, the physiological factors discussed herein cannot be eliminated simply through training, procedural adherence, or even application of appropriate design criteria and job aides. While each contributes to the overall safety and quality of the work environment, and may modulate injury and substandard performance to some degree, these remedies alone cannot overcome normal physiology. Technology cannot ever completely compensate for or eradicate human limitations, though automation designers might prefer to believe otherwise.

While hard and software solutions hold some value as assistants to the given operation, they cannot entirely replace the human-ware in the system. Too often, technological solutions, initially believed to be the "end-all" of labor saving and efficiency applications, actually prove out to have only redistributed workloads. This redistribution typically only results in manual, tedious, or repetitive tasks being exchanged for more demanding cognitive ones [9]. The apparent reduction in workload may offer distinct advantages to users under normal circumstances, yet be more difficult to diagnose when they are not working properly. [9a]

Despite the 24-hour-a-day nature of FIM environments, the limitations and abilities of humans have largely been ignored. If optimum levels of quality, safety and ultimately profitability are to be achieved, the human factors described herein, at a minimum, should be incorporated into any Human and Organizational Factors (HOF) plan [10a]. Incorporation should be undertaken as early in the planning and resource allocation stages of a project as is possible.

HOF plans are increasingly being required in certain commercial and military contract specifications as part of the submission and award review process. It is therefore anticipated that consideration of these factors will increasingly become part of the bid review processes as well as the safety and risk reduction programs of the future.

FACTORS AFFECTING ALERTNESS AND HUMAN PERFORMANCE

The factors affecting the alertness and subsequent human performance that will be reviewed include:

- Time of Day
- Sleep and, Sleep loss
- Fatigue
- Time on Task
- Age
- Medical Conditions
- Other Influences

Time of Day

The body maintains an internal clock or pacemaker that regulates many if not all human biological functions [10]. These functions are considered a "normal function" of human physiology, and follow general to quite distinct rhythms. Many of these rhythms have

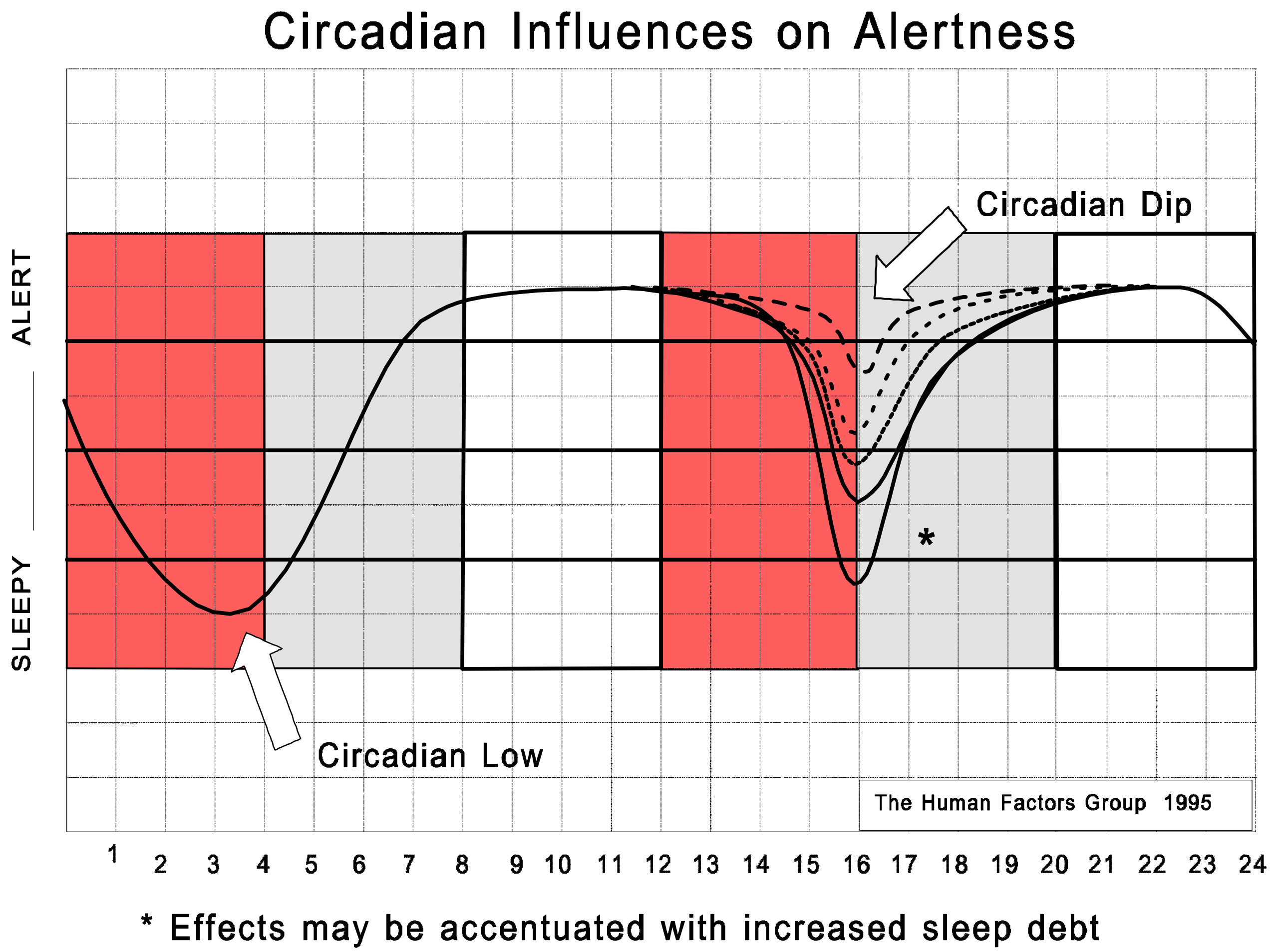

Figure 1. Circadian Influences on Alertness.

been accurately identified, separated, and plotted against time in predictable patterns. The rhythms that most concern this discussion are those that appear to follow a daily cycle and are hence called "circadian rhythms," meaning that they vary on an approximately 24 hour cycle [11] throughout the "circadian day."

Included among these are cycles of core body temperature, hormone secretion, digestion, and those which serve to promote or recall one from the state of sleep.

Figure 1. represents the summation of these cycles as a function of their effect on performance and alertness.

It can be seen that the line describing the summation of these influences has both alerting mechanisms which serve to assist or support the condition of wakefulness throughout most of the daytime-day and early evening, and shutdown signals which promote drowsiness at other times. These shut-down signals typically occur twice a day - once in the early afternoon and the other somewhere after about ten or eleven PM. The first is referred to as the "circadian dip" responsible for the “crash” that many of us feel sometime after lunch. The second begins with the sensation of drowsiness that typically precedes or otherwise promotes the state of nocturnal sleep, and continues throughout most of the night. [12]

This cycle continues whether or not the individual intends or is required to remain awake during the hours approaching either the afternoon “circadian dip” or the early morning “circadian low” described on the plot as shown.

It is important to understand however, that the circadian cycle of influence is something which is not easily changed, adjusted to a new time zone, or adapted to a new work rotation. Rather, the circadian cycle of influence is better thought of as a program which has been "hard wired" into the brain over years of human evolutionary process. It is therefore “normal" for people to be less alert and to feel sleepy at least two times a day. Periods of reduced alertness and therefore performance, may be anticipated as being centered on approximately 0300 and 1500 hours everyday. [12]

Circadian influence is therefore an inseparable function of the performance and safety of humans in any shift working environment. FIM environments are often shift working environments. All work environments should therefore consider and factor what segment of the cycle of circadian influence or "circadian phase" that routine operations are planned or conducted. Allowances and operational countermeasures should be adopted that account for the performance decrements that are likely to be observed at these times.

Though largely overlooked or discounted as simply a “fact of life,” circadian factors are also relevant in production environments wherein personnel are permanently assigned to a particular shift or work period. Even those persons who have theoretically had sufficient time to become habituated to a given rotation, including “9-to-5" day workers, are subject to circadian influence.

As an operational countermeasure, sensitive or high risk operations should be timed in concert with anticipated periods of maximal alertness whenever possible. This precaution is recommended subsequent to numerous studies [13] that have reviewed the effects that various shift work assignments have on normal physiology, cognition, performance, mood state, rate of circadian adaptation, general health, and otherwise. The synopsis of these studies may be broadly simplified as being that:

1) Some adaptation to a given schedule or rotation is possible for most people, if the subject is given enough time to adapt;
2) If the timing of synchronizing cues, such as exposure to light, meals, social interaction, exercise and other cues are appropriate to the desired shift, *and*
3) If desynchronizing cues during the period of adaptation and thereafter are minimized or removed, *and*
4) If the subject takes personal responsibility for maintaining his/her personal life outside of the work environment in concert with the optimal pattern desired, particularly as related to sleep opportunities, exercise, meals, and bright light exposure.

If the above guidelines are not observed, some limited degree of adaptation to a given work schedule will still occur. Achieving optimal adaptation and therefore maximal performance, safety, and job satisfaction however, is complex, perhaps transient, and requires a sense of awareness and cooperation between both the persons in control of an environment, and those subject to it.

Many people working in shift work production environments such as shipyards, often revert to “normal” or approximately normal lifestyles timed in concert with the solar day on days “off.” This has been observed in workers of all responsibility levels no matter what the timing or rotation between night and day “on” or “off” work periods. The net effect of this behavior is that complete adaptation is not ever likely to be achieved [13]. While managing “non-compliant shiftwork behaviors” outside of the production environment is largely beyond the control of the employer, incomplete adaptation will serve to moderate the performance of all personnel.

“Non-compliant shiftwork behavior” is defined herein as lifestyle behaviors that are engaged in at the election of the employee that serve to impede or reverse circadian or other adaptation to a shift or work rotation. Non-compliant lifestyle behaviors are often unintentional and not adopted entirely at the fault of the worker. While many workers are well aware of the symptoms and lifestyle frustrations that working rotating and evening shifts create, few are believed to understand the underlying circadian physiology that causes or could be advantaged to abate these effects.

Little if any education is typically provided the would - be shift worker at the time of assignment, and perhaps less pre-employment screening is performed than should be. Failure to educate personnel in the hazards and side effects of shift work, or to provide adequate medical screening, enables personnel to enter the production environment who medically, physically, or emotionally should not be. In fact, production environments already contain many people who are not suited to or are otherwise dissatisfied with shiftworking lifestyles, particularly night shifts.

Therefore, all personnel responsible for the design, coordination, or planning of the production environment, as well as those who are required to function within it, are urged to consider the circadian phase within which a given operation is to be conducted.

As a general rule: Time the most dangerous or demanding tasks for those periods in the day that personnel are most likely to be alert.

Sleep and Sleep Loss

Inseparable from the discussion of circadian influence and phase are the issues surrounding sleep, sleep quality and quantity, sleep loss, and recovery sleep. Treatment of these topics alone requires considerable time and explanation. A general understanding of the underlying physiology, remains of critical importance if improvements in the operational environment are to be effected. In brief, these subjects may be summarized as follows.

> "*Sleep is a vital physiological function. You need to eat, you need to breath, and you need to sleep*." [14]

If the body is deprived of any of these, it will in some fairly predictable amount of time, die. No one can exist without these basic needs being satisfied and performance becomes progressively impaired in all people [15] as the duration of wakefulness is prolonged.

The average person requires approximately 8 hours of sleep [16], however some people require less and others substantially more. Regardless of the basal amount of sleep individually required, when the available sleep opportunity does not allow for an individual to achieve the amount “normally” required, "sleep debt" begins to accrue.

Sleep debt is analogous to a bank account or checking reserve that may be tapped to some limited extent, accruing in an approximately linear fashion as incurred. Accruing this debt will cause the physiologic need for sleep only to increase. This increase is described by the term “sleep pressure.” Sleep pressure increases throughout the period of wakefulness and is manifested in the sensation and tendency of the body to achieve the restoration it needs and can only get through the state of sleep. The most obvious indicator of increased sleep pressure is the sensation of sleepiness. Sleepiness can be scientifically measured and correlated to the alertness of the subject being tested.

At some point in time, and particularly when alerting mechanisms are removed during declining or “de-alerting” circadian phases, the sensation of sleepiness may be so overwhelming as to cause *uncontrollable*, and often dangerously undesirable, sleep episodes. These episodes range from a mild sensation of distraction or "day dreams," to the extreme head-bobbing drowsiness and/or observable sleep episodes that most people have experienced at some time or another.

Perhaps the most alarming of these unplanned and uncontrolled sleep episodes takes the form of what is known as a "lapse" or "micro-event." These occurrences may last from fractions of a second to several minutes, and occur at any time of the day or night throughout periods of perceived or required "wakefulness."

Stimulus, information, and even conversation occurring during a "micro-event" may not register with the affected individual *at all*, even if the eyes remain open.[24] Much like the well known anecdote about “the lights being on...but nobody’s home,” a lapse or micro event is a state of disassociation with the environment that a person is immersed in or controlling. Disassociation with the immediate or distant environment is not always complete. In some cases humans have been reported to be able to answer alarms or perform actions within sleep episodes or lapses, without recognition or recollection of having done so.

It is possible that humans may experience lapses during the performance of typical production tasks such welding, spray painting, or monitoring production equipment, without the individuals knowledge. Such acts of commission or omission may result in errors such as welding flaws, painted areas being over or under coated, and other errors or inefficiencies that become latent defects or must be reworked.

There are also times in any stage of the production cycle when coordination amongst participants is required if accidents or critical errors are to be averted. Involuntary performance, disassociation from the task or environment, and inappropriate acknowledgement of an action, alarm, or other cue can lead to catastrophe.

While no one can predict when a "micro event" will precisely happen, it has been determined in numerous studies that micro events are more likely to occur in people who are sleep deprived than those who are well rested. How many mistakes, injuries, near misses or accidents, or the cost of these, that are related to lapses in consciousness is unknown. It has been established that the amount of sleep preceding an incident is an important factor in accident investigation, error detection and therefore loss prevention [17].

The quantity of sleep alone is not sufficient measure of the degree of restoration likely to be achieved. The *quality* of sleep is equally if not more important than the quantity achieved. Virtually all personnel in and out of the production environment have experienced nights of "sleep" wherein eight hours of time spent in bed have not been restorative. Many people have also experienced occasions when brief naps have seemed more refreshing than longer sleep episodes. The subjective difference between the restorative value of sleep episodes of differing lengths is attributable to a number of complex factors. Including, the time of day that sleep is attempted and the effect that other factors like caffeine, alcohol, and various over-the-counter medications have on the quality of sleep possible.

Many substances alter normal sleep patterns or "sleep architecture." The consequence of this alteration is generally poorer quality sleep and subsequently impaired or less than optimal performance thereafter. To understand the potential effects of the sleep modifying drugs that will be discussed later, it is important to understand that sleep is not a homogeneous state but divided into at least two distinct types.

The states of sleep are described by specific patterns of brain wave activity, though they are named by the degree of eye movement (rapid and non-rapid eye movement, or REM and NREM respectively) that we are likely to experience within these states. NREM may be divided into four distinct stages, 1 through 4, with stage 1 being lightest and stage 4 the deepest sleep. REM sleep is characterized as "the dream state" and as different from NREM as is sleep from wakefulness [12, 24]

Each type and stage of sleep plays an important role in restoring the physiologic and psychologic needs of the body. Depriving the body of either for some period of time by abbreviating sleep periods, ingestion of substances that modify sleep architecture, stress, or other means, will have both physiologic and psychologic effects. These effects will eventually manifest themselves during wakefulness as micro-events, depressed or altered moods, impaired performance, and in other ways..

The accepted correlation between the subjective and physiological effects of sleep loss as related to extended periods of wakefulness, the quality and quantity of sleep achieved, or otherwise, is embodied in the study and sensation of "fatigue." [18]

Fatigue

Fatigue as it is used in this context, is a general description of those factors that cause or contribute to performance decrements in humans as a result of extended operations, shift work, transmeridian travel, sleep deprivation, personal stress, and other factors [18]. Factors contributing to fatigue are considered intrinsic to any production environment.

Fatigue can be experienced and expressed in both physiological and subjective terms and may be measured fairly accurately in a controlled environment. Symptoms of fatigue include drowsiness, burning or itchy eyes, headache, back pain, stress, anxiety, depression, alienation, attention deficit, the inability to concentrate, memory loss, confusion, mood swings, and gastrointestinal disorders, amongst others.

These subjective expressions of fatigue may be further quantified to include observable symptoms very similar to those following alcohol consumption. These include:

- loss of balance and disequilibrium
- selective exclusion of inputs
- fixation on selected inputs
- inappropriate risk behavior and/or assessment
- shift from external to internal focus
- depressed motor skills and coordination
- increased subjective error tolerance
- exaggerated corrective action and overcompensation
- decreased cognitive ability
- increased reaction time
- global performance decrements, including
    - reduced visual acuity,
    - oral detection and discrimination, and
    - other sensory related impairments

The symptoms described above have significant effects on the safety of the production environment. It is of fundamental importance that persons responsible for the control of any production environment recognize that *no one* is immune to the effects of fatigue.

Most people will not generally admit feeling or having experienced these symptoms however until long after the effects have obviously manifested themselves in their affect and performance. This is particularly true in production environments wherein a sense of imperviousness or superhuman capability has been forged as a desirable identity. The behavioral tendency or trait associated with this denial process is sometimes described as the "Superman phenomena." In fact, the process of denial associated with fatigue may be as strong as it is amongst individuals who are addicted to nicotine, alcohol, caffeine, and other substances [1].

Resistance levels to the admission of fatigue has both physiological and psychological origins. A fatigued person cannot feel or perceive the same sensations as a normally rested person, either within or without of the body. Consequently, fatigue affects subjective assessment of wellness and fitness for duty. Much in the same way that the neurologic effects and psychological based denial processes that attend the chronic abuse of alcohol and other substances, serve to bias personal subjective recognition [19] of the disease process. The last person to recognize fatigue, and often the most unreliable person to ask regarding personal performance, is the individual that is already tired [12]. This is true for many reasons including the alerting mechanism that just asking an individual represents. Psychosocial factors also effect the objectivity of responses. Concerns for job security, social acceptance amongst peers, and certain cultural factors serve to inhibit truthful responses from many people. Supervisors and managers cannot rely on personal subjective estimates of fatigue or alertness when evaluating the fitness for duty of personnel or the safety of an operation.

Fatigue also affects risk perception and risk taking behavior. Fatigued persons are more prone to fail to recognize, inaccurately asses, or choose to take risks that a normally rested person would consider inappropriate to the circumstance [20]. The shift in risk sensitivity and acceptance may occur simply to "get it over with," [12], presumably to get some sleep thereafter.

The effects of acute fatigue may be mitigated by a variety of operational countermeasures, including strategic napping, caffeine, and certain drugs [12]. Many countermeasures are easily and inexpensively implemented in the production environment. Countermeasures are particularly effective when augmented by survey tools and general awareness training programs specifically designed to explain the role and importance of physiological factors on human performance.

It is not possible to maintain performance via countermeasures indefinitely however. At some point in time nevertheless, the individual must be removed from the operational environment and given the opportunity to achieve preferably nocturnal sleep, or sleep appropriately timed in concert with their adapted rhythm.

Typically, restoration to "normal" performance may be achieved after two nights [21] of nocturnal sleep, though this may vary from person to person and is interrelated with the quality of sleep achieved during that time.

Repetitive abuse of the body via sleep deprivation, indigenous and prolonged operational stress, rotating shifts, and/or abusive lifestyle habits such as excessive alcohol consumption, [22] will lead to the condition or state of "chronic fatigue." Chronic fatigue results in an overall decrease in performance, wellness, and emotional state that may be difficult to impossible to rehabilitate by sleep alone [23].

Figure 2 has been included to demonstrate how sleep maintenance or loss may be compared to performance over time. The top line represents the probable performance of a person that is allowed to achieve as much sleep as physiologically needed, known as "sleep satiation." Sleep satiation is very hard to achieve in today's modern society. It is estimated that a substantial portion of the American society [14, 24] does not consistently achieve satiation, even when working normal "9-to-5" jobs and living a typical lifestyle. Shift workers in many production environments have also been determined to accumulate sleep debt. Achieving sleep satiation is therefore considered difficult, second jobs, grad school, children, and recreation not withstanding.

The middle line in Figure 2 represents a person who is allowed enough sleep to maintain some lesser level of sleep satiation and therefore performance. This less than optimal level may or may not be adequate to guarantee their performance in a given production environment. By far the majority of production workers fall into the middle category in so much as they would probably be able to achieve more sleep if time were available. Hence, their performance would likely be improved [24] by doing so. Humans routinely perform tasks at differing levels of sleep deprivation. Typically this performance may in fact be "adequate" enough to "safely" drive a car to work or otherwise function as a member of society. No estimate or evaluation is made as to whether this level of performance is appropriate to the requirements of the production environment however. Even if a production environment requires driving the same or similar vehicle as part of the work environment, the same degree of freedom, safety margins, and operating guidelines do not exist in both environments. Neither are the risks inherent to either environment the same or as clearly defined.

The bottom line in Figure 2 shows a person who becomes successively sleep deprived by only one hour per day less than is required to maintain performance at their normal "adequate state" or equilibrium. It is clear that such a person is quite sleep deprived and obviously impaired at the end of the week .

Performance at this level of sleep deprivation is inadequate in an environment that requires maximal alertness, response, and/or productivity. The degree of impairment observed in humans subsequent to seemingly small but cumulative amounts of sleep debt raises some poignant questions in the production environment.

What is the appropriate length of a work week, and individual shift, and the length of time one remains on, or has to adapt to, a given rotation? The answer to this question is in part embodied in the study of performance as a function of work duration, which is often referred to as the study of "time on task."

Time on Task

If fatigue is discounted as a factor in a normally rested person, how long can he/she remain on task before performance is observed to decrease to a level that is considered unsafe or inefficient? The exact answer varies with each individual and will vary within the same individual depending on the circumstance and the demands of the operational environment. Some generalizations may be applied to all people nevertheless, which are synopsized as follows.

Routine operations. No matter the length of the work period or shift, the amount of time "off," or the amount of time off watch but on call, schedules need to be designed and arranged to allow personnel to achieve their basal sleep requirements. Time off should be of sufficient duration as to allow personnel time enough to achieve preferably one consolidated sleep episode provided in concert with their personal daily rhythm. Additional time should also be provided however is required to allow employees to accomplish tasks that are typically required of "normal" members of society. Particularly in the case of production environments that also maintain a resident staff or perform work on the road, sufficient "off" time for travel, personal hygiene, laundry, meals and digestion prior to sleep should be provided as well. When operational demands such as those arising in response to production deadlines, emergency repairs, or natural disasters, cannot provide for all or even most of these considerations, the potential for sleep debt to accrue is increased. Consequently the likelihood that human performance, reliability, and mood will at some point deteriorate is considered inescapable.

No universally accepted work-rest guidelines are known to exist in or for the production environment, though various regulatory and labor union guidelines have exist for some time.

Other operational environments have studied the issue of time on task in some depth however. For example, in the commercial air transportation industry, research by NASA and others have lead to guidelines being published [21] which suggest that not less than 10 consecutive hours of rest be provided personnel following a duty period of not more than 10 hours.

Where this cannot be provided, and/or when work periods engage or approach times of circadian low (between 0200 and 0600 hours), rest periods should be increased to allow more recovery time. In cases where extended operations and prolonged periods of wakefulness are required, not less than two nights of recovery sleep should be allowed prior to reassignment.

These recommendations are not considered extreme and parallel the normal eight hour shift or business day that members of the management and administrative staff typically serve. Many organizations require production workers to work four ten or even twelve hour shifts however, particularly in response to seasonal demands or opportunities to do so. As do many production environments require or encourage overtime hours to be worked on a routine basis. These practices have the same net effect on the employee however, by extending time on task and therefore reducing the amount of rest and sleep opportunities available thereafter.

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Present guidelines also assume that all employees work in a relatively comfortable environment, which means one that is not uncomfortably hot, cold, noisy, excessively vibrating, or that requires some unusual or strenuous posture or physical work attitude.

Environmental factors alone may cause a person to fatigue quickly, internalize thoughts and focus on the stressor to the detriment of other sensations, inputs, and information. Further do present guidelines presume that the employee is able to maintain a normal eating pattern, remains hydrated, and can relieve themselves when required.

Where these environmental conditions and personal accommodations are not provided, and there are others not mentioned that are similarly important, then performance and efficiency will be dramatically reduced at some point.

Routine schedules and environments should be reviewed and structured to minimize the probability that fatigue will accrue beyond levels that may be rehabilitated by the off or sleep time available thereafter.

Sustained Operations. Where the work-rest provisions referenced above cannot be maintained over prolonged periods of time, which is defined as greater than 2-3

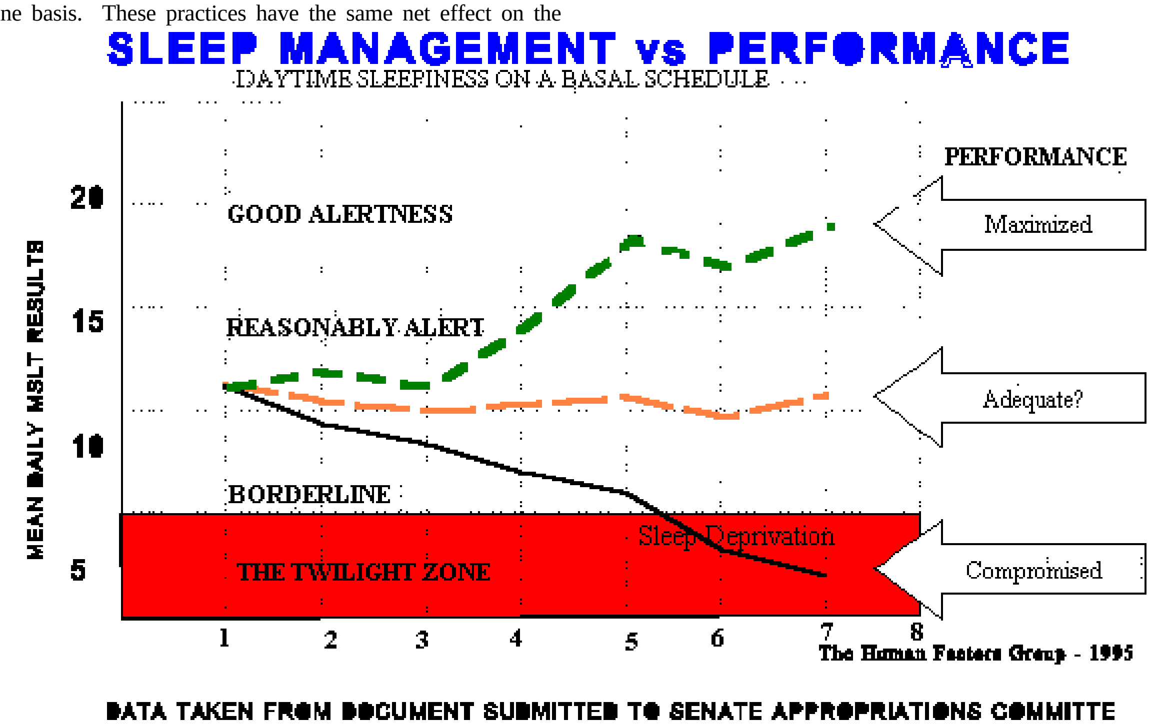

Figure 2. Sleep Management vs Performance

days for the purposes of this discussion [15], performance will deteriorate. Recent study of the brain's ability to metabolize glucose, which is the fuel required to sustain basic cerebral functions, has determined that a dramatic decrease in *global* brain functionality occurs at approximately the 18 to 24 hour of wakefulness mark. [15]

This decrement affects all major brain functions that are considered important to vigilance, performance, and reliability. Including those associated with cognition, eyesight, hearing, coordination, and other senses.

Regarding the study cited which was performed by the Walter Reed Army Institute of Research, the subjects tested were 21-29 years of age, in good health, and possibly in better physical condition than the average production worker. Subjects also remained in a controlled environment for the duration of the test. Subjects therefore did not leave the test to moonlight at second jobs, use or abuse recreational drugs like alcohol, maintain familial responsibilities, or engage in excessive physical activity after work.

In considering the significance and relevance of this study to the production environment, the results may represent a "best case" scenario. It is likely that the average population in a production environment therefore experiences at least the magnitude of the effects reported. Significantly greater performance decrements may be observed in production workers when multiple performance modifying influences such as alcohol are considered in addition to the effects of sleep loss resulting from extended periods of time on task.

Nevertheless, the results of this study demonstrate that no person should be expected to remain functionally awake in an operational setting for an extended period of time. Restorative sleep opportunities must be provided and utilized for sleep. Oddly, anecdotal survey of military personnel engaged in sustained operations has suggested that it is the highest level of command who are most likely to subject themselves to extended periods of wakefulness. This statistic leaves one to question whether command decisions made during day two, three, and so on are as considered or rational as would they have been if sleep had been designated as an operational priority, as well.

In the production environment it remains only academic to relate the military anecdote provided, to the stresses that deadlines, critical path maintenance, milestone inspections, launchings, and sea trials all give rise to.

Where commercial viability may be the "war" being fought by management and supervisory "commanders," with production worker "troops," it cannot be ignored that real lives are nevertheless at stake. Responsibility for the quality and safety of the product or service begins in the design and fabrication stages of any product and extends throughout the operational life cycle of the product (vessel), thereafter.

For these reasons, extended periods of service, including "all-nighters" undertaken by the design staff, are to be avoided. Prolonged periods of overtime or even *volunteer* time should also be curbed in the interest of safety, quality and overall productivity.

Many in the production environment would argue that overtime is an inescapable, if not financially desirable reality of equipment failure, supply shortages, change orders, and other delays. Those bearing fiduciary responsibilities might wisely review why these hours are required in the first place. Some percentage of extended work periods are considered inevitable, though personnel should be managed to ensure that fatigue does not become the root causes of further delays, accidents, degraded performance, safety and quality overall.

Age and Performance

One of the most controversial subjects regarding human performance centers on the issue of age as a function of ability, cognition, vision, reflexes, and performance overall. This controversy is to be expected considering the aging nature of the American workforce, and for a variety of psychosocial reasons as well. Valid arguments regarding the role and value of experience, training and professional skills achieved over time exist that oppose arguments in favor of the physical benefits that youth to some degree affords. This review will dealing with age related performance strictly as a function of normal aging.

It is well established that there are certain clear physiologic differences in humans of varying ages that affects their ability to perform as they grow older. One significant difference between normal older and younger humans is related to the ability of older people to achieve and maintain the state of sleep.

Throughout life the quality and quantity of the sleep people can achieve changes as does their ability to achieve consolidated periods of nocturnal sleep. Even as early as age fifty or so [18, 25], undisturbed sleep periods get shorter and there is an increased tendency for daytime napping.

The inability to achieve undisturbed sleep affects both the quality of daytime alertness and the ability of older people to achieve quality recovery sleep. The performance decrement which may result is only exacerbated by evening or irregular shift work in general, and following prolonged periods of sleeplessness.

Physiologic sleep needs do not substantially change through adulthood. Only the ability to achieve the states and stages of sleep changes. Older persons still need to achieve their basal sleep requirements. Many older persons subjectively experience and rate the effects of sleep loss significantly higher than would they have earlier in their lives.

Other physiological changes occur as a normal function of aging as well, each of which affect our ability to perceive the environment we are part of. Changes typically occur in eyesight that may be generalized as decreases in our visual acuity when observing moving targets [26], whether they be moving by us or we them.

Significantly higher degrees of contrast are also required to achieve the same visual acuity at age fifty as would a twenty or thirty year old person require in similar environments. Glare sensitivity also increases with age, and farsightedness may progressively develop throughout life, becoming more noticeable after age 40 or so. [8, 27].

Humans also tend to be less tolerant of heat stress as they age, particularly if they are in poor physical condition or consume alcohol before or during exposure [28].

These normal changes are not presented to jade or otherwise color the practice of employing people of any given age bracket. These examples are simply intended to emphasize the importance of these human factors in the production environment when considering the task and level of performance required.

Clearly, expecting an older individual stationed in a hot operating station, such as in a security post or crane cab [6] overlooking the glaring water, to maintain vigilance and/or detect sudden or quickly developing changes in an operational setting that is generally serene, would be a less than optimum match of human and task. Tasks and environments should be designed with both the work environment, the operator, and the variability in operators in mind.

Medical Conditions

Certain medical conditions exist which affect the ability of humans of any age to perform in the operational environment. These include obvious physical restrictions such as heart disease and general obesity, whether genetic or otherwise in origin. Less obvious medical conditions exist that impair human performance in the production environment. These conditions often exist without the subjects awareness.

Of these, sleep disorders such as excessive snoring and sleep apnea are most likely to exist without the subjects knowledge. Clear correlation between the sensation of excessive daytime sleepiness and/or the associated performance decrements experienced during waking hours is therefore often not made by individuals and physicians.

In the case of excessive snoring and sleep apnea the affected person is unable to achieve the stages of sleep required to ensure physiological and psychological restoration. This occurs essentially because the act of snoring and the cessation and re-commencement of breathing, act as alerting mechanisms and cause repetitive awakenings. Awakenings prevent consolidated and deeper stages of sleep.

A significant percentage of the population is believed to suffer from these and other sleep disturbing disorders. It is further estimated that many of the symptoms of prolonged sleep impairment, such as hypertension and CHD, are treated without the root cause ever being identified as sleep related.

Unfortunately, many of the medications prescribed have sleep inhibiting side effects that treat the symptom observed but only further worsen the underlying root cause.

Many people also suffer from "insomnia," either as a medical condition or as a transient symptom that is most often psychological in origin and associated with life-stress. Shift workers also complain of recurrent insomnia when attempting to adapt to changes in work rotations.

In response to these complaints a variety of sleep promoting formulations are prescribed. These include medications that either help to promote or maintain consolidated sleep. Many sleep medications alter sleep architecture however and it is important to select the appropriate drug for the operational environment envisioned.

Of specific concern is the half-life of the drug in the system, as well as any rebound effects which may follow use and “carry over” into the production environment. As a general rule, it is best to take only the ***"lowest effective dose for the shortest possible time"*** [12]

Other Factors

Many other factors serve to impair quality and safety of a production environment. Some of which are the direct result of countermeasures specifically designed to avoid this from occurring.

Of these, three stand as most significant and likely to be observed in the production environment. These are caffeine, alcohol, and various OTC medications that are readily available, widely utilized and often little understood.

Caffeine. Caffeine is an effective stimulant, however it is easy to unknowingly abuse caffeine, often to the point of developing a dependency to the drug. While coffee is perhaps best known and the most widely used operational stimulant, some types of tea in fact may be brewed to deliver more caffeine per serving. Caffeine is also present in a variety of innocent foods, such as chocolate, cocoa, and most cola-based soda. Table One has been included for reader reference [29], and demonstrates the manner in which certain products such as Mountain Dew® may contain significant amounts of caffeine, despite that some products are not classically thought of as stimulants. What many caffeine users do not realize is that humans develop an almost immediate tolerance to the drug. A given dose routinely administered, be it in the form of coffee, soda, or caffeine pills, will not have the same effect as did the first or second administration [16]. Habituation to caffeine occurs quickly. Many psychosocial processes are associated with the addiction process as well. Certain of these serve to facilitate the normal human tendency or desire to maintain some repetitive state or sensation.

Brand	Caffeine	Brand	Caffeine
Mountain Dew	52	Diet Pepsi	34
Tab	44	Coca-Cola	34
Sunkist Orange	42	7-up	0
Dr. Pepper	38	Sprite	0
Diet Dr. Pepper	37	Diet 7-up	0
Pepsi Cola	37	Hires Root Beer	0

Table 1. Caffeine Content of Various Products

This desire in turn leads to increased dose over time and dependent behavior rapidly develops.

Caffeine abuse has many side effects. Including, induced tension, headache, mood swings, vision impairments, anxiety, and central nervous system interference. Caffeine also impairs sleep onset and modifies sleep architecture. For this reason, caffeine consumption should be limited to times of operational necessity and avoided several hours prior to planned periods of sleep.

Alcohol

Alcohol is a drug that is easily sourced. Repetitive use often leads to substance dependent or abusive behaviors. The negative effects of alcohol on the central nervous system are well known however, and include increased response time, loss of equilibrium, and general cognitive impairment. Alcohol is also one of the most widely used recreational, relaxation and sleep aides in the United States, even by people who admit that they are already tired.

The FACT is that alcohol is a powerful sleep *suppressant*, and that the sleep promoting effects which are seen as initial benefits, are actually short lived. Specifically, alcohol modifies sleep architecture generally by suppressing REM sleep, and by causing frequent awakenings for a variety of reasons. These include withdrawal effects that are normal to metabolizing the drug, and awakenings stimulated by the need to relieve bladder pressure. Periods that might otherwise be advantaged by sleep or less physically taxing/damaging activities should not include excessive alcohol consumption.

Despite these facts, and despite the random testing programs and strict operational and legislative controls in effect, the use/abuse of alcohol is somewhat pervasive in production and corporate environments.

Of significant concern is the excessive recreational use of alcohol during meal periods and “after work” or on “days off.” Many individuals also believe that alcohol consumed in moderation, particularly at meal times, will not effect their performance enough to be considered of significance in the work environment. Subjective estimates of blood alcohol concentrations of ".04" or otherwise established maximum "safe" limits, are not guarantee of safe performance in the production environment. Many users of alcohol incorrectly believe that:

- Recreating with alcohol in close proximity to scheduled work periods is of no consequence, so long as enough time is allowed to "sleep off" any excess blood alcohol concentration they may have achieved, and
- That "sleep" thus promoted, is in fact restorative enough to return them to "safe" levels of performance, though admittedly not necessarily at "peak efficiency."

Such "normal" or "reasonable man" behavior can be demonstrated to result in personnel of all status reporting for work at or in excess of allowable blood alcohol concentrations, surveillance and random testing notwithstanding. Excessive consumption of alcohol will amplify existing sleep debts and result in further accumulations of sleep debt. As described earlier, this debt will have to be repaid by recovery sleep at some time, and possibly promote the occurrence of micro events and even observable sleep in the production environment.

Further may alcohol and loss of sleep modify personal estimates of risk and risk perception. This shift in risk perception does not categorically result in increased risk taking, but may do so.

Particularly within several hours of planned sleep episodes, after periods of prolonged wakefulness, and during work periods, the consumption of alcohol is strongly discouraged.

Over-The-Counter (OTC), Medications

Many people self medicate, at least initially, when they are not feeling well. Many OTC medications are available to the public, some of which have been recently released that were previously available only subsequent to the advice of a physician, by prescription. A wide variety of formulations must now compete for market share via marketing strategies aimed at achieving consumer loyalty, defeating generic availability, word of mouth advice, and otherwise. This plethora of products leads to confusion on the part of the user, and potentially inappropriate drug selection and administration. In part this confusion is promoted by products and packaging that does not effectively communicate the intended use or potential side effects of ingredients.

For example, products offering cold and flu symptom relief often contain alcohol, caffeine, or both, as well as other ingredients which serve to interfere with sleep and performance while "awake." Many products also advertise components in manners that are not universally used by industry or understood by the consumer such as "No-Drowsiness" or "PM" formula descriptions.

Other products promote drowsiness purposely or as a side effect, including some well known allergy, sleep, and motion sickness formulations. In part these effects are related to the ability of certain drugs to affect the central nervous system, which may mean that response times are increased. Clearly where machinery, cranes [6], high pressure spray equipment, and welding/cutting operations are concerned, this impairment is potentially dangerous, as well as operationally inefficient.

Personnel engaged in these operations should consider the effects that all medications may have on their vigilance, response time and performance, before they are ingested. Management should educate personnel in types and availability of drugs that are "safer" to use than others, such as Seldane™ and others that do not cross CNS barriers [1, 19].

Nevertheless, reactions to dose and type are individualistic and all medications should be "ground tested" either at home or out of the sensitive environment, prior to their being utilized in the production environment.

Certain OTC medications have been recommended for occasional use as sleep promoting aides during times of transient insomnia. One such drug, diphenhydramine, is sold under several names including Benadryl.™ This particular drug promotes drowsiness in many people without long lasting side effects. It may be taken occasionally in anticipation of sleep when mid-sleep period operational demands are not anticipated.

All drugs, including caffeine, alcohol, prescription and OTC medications have "half-lives." The half - life of a drug should be determined and considered in the timing of administration, prior to ingestion if hang-over effects are not to invade periods of required alertness and performance.

CONCLUSIONS

Normal physiological and psychological tendencies exist which should be factored into the design, planning, management and operation of FIM environments. These include in part the time of day, circadian phase, time on task, fatigue, age, and the use or abuse of substances that are considered a normal part of society. Many employees do not understand the significance and effect of these factors on their safety, health, and performance. Further is there a general lack of knowledge in the production environment to the effects of shift work on the body as a whole. This lack results in "non-compliant" shift work behaviors both on and off the work site.

Certain psychological, psychosocial and cultural factors serve to complicate treatment of these issues, as misconceptions are well established and pervasive. Nevertheless, these factors play an important role in supporting or undermining the alertness, vigilance, reliability, and ultimately the quality and safety of production personnel. Sustained and overtime operations are attended by progressive performance decrements. Overtime and extended operations, even when voluntary, should be limited in the interest of safety and efficiency.

These important considerations should therefore be factored for in the design of the physical and organizational structure of the production environment however possible. Present OSHA regulations and industry standards do not provide sufficient guidance to prevent the effects of, account for, or otherwise implement effective countermeasures against these factors. Owners, operators, subcontractors and other stakeholders in the production environment are therefore encouraged to address these issues internally and publicly in advance of regulation.

Not discussed in this presentation remain many issues that are also directly related to the reliability and efficacy of any production and risk management system that are not exclusively physiologically based. Neither have the effects that fatigue has on mood state, risk taking behavior, and communications been adequately treated.

These intentional omissions and considerations notwithstanding, the two single most effective improvements which can be most economically applied to improve the safety and efficiency of the production environment overall, include:

- Educating those most affected by or in the operational environment, their support systems, co-workers, and families in the underlying physiology surrounding human performance, and the lifestyles associated with shift work in production (FIM) operations, and

- Sleep.

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